# Mine Emergency Communications Partnership
# Phase I, In-Mine Testing

## Selecting systems for preliminary underground testing

After the Sago and Alma Mine disasters, MSHA received many (over 80) proposals from manufacturers of communication technology for obtaining MSHA approval for use of their systems in gassy areas of underground mines. MSHA reviewed the proposals, first screening for systems that do not rely on a wire back-bone to operate, thereby increasing their chance of remaining functional after a disaster. They then looked at the different types of technology being proposed, e.g. wi-fi mesh network, ultra-wide band, medium frequency, and low frequency, as well as the function of the technology, e.g. miner tracking, through-the-earth, and in-mine communications. From this the candidate technologies were classified into groups to ensure that each major group would be included in the first round of in-mine testing. And lastly, MSHA examined the proposed technologies for evidence that the systems could be commercialized within a reasonable timeframe. Seven communication systems were initially selected for preliminary field tests based on the criteria above as being the most promising for application in underground mines. These are described briefly in Attachment I to this document.

## The test process

The Mine Emergency Communications Partnership developed a protocol for the initial testing (Phase I). CONSOL Energy, a member of the Partnership, offered their McElroy Mine near Moundsville, WV as a test site for system evaluation. McElroy Mine is an underground coal mine, with extensive mine workings, a seam thickness of about 6 feet, overburden thickness between 270 and 800 feet, and track and belt haulage. The workers at this mine are represented by the UMWA, which is also a member of this Partnership.

Two days of testing were allowed for each system. In general, the testing sought to determine, in-mine line-of-site communication capability, in-mine non-line-of-site communication capability, tracking capability (if part of system), and through-the-earth communication capability (if part of system). The test procedure was as follows:

*For in-mine communications systems*:

1) Determine line-of-site communications capability.
   - Set up base unit in main mine entry (track haulage).
   - Walk down entry with a mobile unit until the communications stopped. Measure that distance.
2) Determine non-line of site communications capability.
   - Base unit is still in main mine entry.
   - Walk the mobile unit through an undulation in the entry to determine the ability to maintain communications.

- Walk the mobile unit into a cross-cut entry to determine communications capability.
- Walk mobile unit into an adjacent parallel entry through a block stopping to determine communications capability.

3) Determine the effect of potential mine interferences on system operation. A belt haulage entry was used to conduct this test.
   - Base unit is in belt entry.
   - Walk the mobile unit in the belt entry to determine communications capability. Measure the distance when communications is lost.

*For Through-the-earth Communications:*
Surface points had been surveyed to correspond with an underground location on the mine map. Points corresponded to 270, 500, and 600 feet of overburden. One crew went in the mine to the initial test location, and another crew to the corresponding surface location. Tests started at the 270 foot location. If successful, each crew went to the 500 foot location, and so on. Whatever the technology being proposed by a vendor, beacon signal, data, or voice communication, it was tested at each depth of cover.

*For in-mine tracking capability:*
Wireless nodes were placed at different points along a mine entry. A mobile node was moved along the entry. A computer at the based location was used to display relative position of the mobile node.

**Summary of testing**

This was the first in-mine test for most of the systems. In fact, most of the vendor personnel had never been in a mine before, and it was a real eye-opener for them. Conditions and the environment were not what they expected. They were surprised by the harsh physical environment, e.g. temperature, water, dust, confined spaces, as well as as the harsh electromagnetic environment, i.e. potential noise interferences from belt drives/motors, trolley wires, substations and overhead powerlines (on the surface). One vendor said that they had never seen so much noise interference at any facility that they had previously examined. None of the systems has an MSHA approval for use in potentially gassy mine atmospheres (except Geosteering PAD). MSHA is committed to helping vendors through the approval process – but first they must address technical functionality issues.

The original plan was to test seven systems, as mentioned previously. One vendor (Vital Alert) stated that they did not have the funds to travel to the mine site and then withdrew from the test. The systems tested were Rajant, Time Domain-Concurrent Technologies, Geosteering, Innovative Wireless, Kutta Consulting and Transtek. All of these systems can be described as in the prototype stage with varying degrees of development still needed. None of the systems is ready for commercialization.

In general, most systems were limited to 1000 to 2000 feet line-of-site communications. One exception was the Kutta Consulting system, which provided good voice communications at 5387 feet from the base. This was non-line-of-site operation through an undulation and through an s-turn. It should be noted that this is not the maximum distance that the Kutta system was able to communicate. Maximum distance could not be determined due to unavailability of the main-line track entry used to conduct the testing. This significantly greater range as compared to the other systems was due to the systems operation in the medium-frequency range which tends to couple on to any metallic objects in the mine and re-radiate throughout the mine. There is high-level of enthusiasm for a system that includes medium-frequency capability, because such a system could potentially work well in a post disaster environment, and could be economically and technically viable. Moreover, such a system could be used for routine communications in the mine.

For through-the-earth testing, most vendors complained about the noise interference at the mine site from substations and power lines. While some of this interference would disappear in a post-disaster environment, much of it could remain. Despite the interference, one vendor was able to receive a beacon signal on the surface from underground at the 270 foot depth. Another vendor thought that they received a beacon signal at 270 and 500 foot depth, but this could not be confirmed within the parameters of the Phase I testing. One vendor was able achieve two-way voice communication between the surface and underground at 270 feet. This is an encouraging finding. See Table 1 for summary of Phase 1 test results.

**<u>For the future</u>**

The good news is that some very promising technologies are being presented for testing, and of these, some are showing real potential to provide viable post-disaster emergency communications. The bad news is that all of them will require additional technical and proof of concept work before they will be ready for commercialization and MSHA approval testing. There is insufficient data to accurately estimate how long it will take to commercialize the most promising technologies, but with appropriate funding, a 36 month time horizon is within reason. Several of the vendors said that they would like to make modifications to their systems, software, antennas, and hardware to achieve better performance now that they have a better understanding of the mine environment, and the functional constraints of a mine communications. A few of the vendors were optimistic that they could do better.

The Partnership, as well individual members, will continue to work with these vendors to provide technical input and to conduct follow up testing. A Phase II testing protocol will be established as systems become available for additional testing. Additional Phase I testing of promising systems will be conducted. After successful demonstration at the Partnership's test mine (McElroy), further testing should be conducted at other mines to assess performance under different mine conditions.

# Preliminary Test Results

| | In-mine, Line-of-sight range (ft) | Through-the-earth range (ft) |
|---|---|---|
| Rajant | 1500 | N/A |
| Time Domain/Concurrent Technologies | 2000 | N/A |
| Geosteering | 1000 | 270 (Beacon) |
| Innovative Wireless | 1800 | N/A |
| Kutta Consulting | >5387 (was non-line-of-site) | 270 (Beacon) |
| Transtek | N/A | 270 (Voice) |
| Vital Alert (Withdrew) | ---- | ---- |

Table 1. Summary of Phase 1 Test Results

**ATTACHMENT I**
**BRIEF OVERVIEW OF EACH SYSTEM SCHEDULED FOR PHASE I TESTING**

## Kutta Consulting's Subterranean Wireless Electronic Communications System (SWECS)

SWECS is being developed by Kutta Consulting for the U.S. Army Communications and Electronics Research, Development, and Engineering Center (CERDEC) in Fort Monmouth, NJ through a Small Business Innovative Research (SBIR) contract. The system consists of a digital radio (8cubic inches, 8 ounces), a PDA type of display, and a small, portable antenna. It will work off of line power with battery backup or solely on battery power, depending on final deployment requirements. The system is designed to provide two-way voice, text, and image transfer through a stationary multi-node network and through the earth. The nodes will establish an ad-hoc mesh network which will provide redundancy in case of individual node failure. Portable units will communicate with the stationary nodes and peer to peer.

A key feature of this system is the use of a Software Defined Radio (SDR). The SDR will allow transmission and receiving of signals using several different frequencies depending on the goal of the transmission. The only requirement will be that an antenna matched to the frequency range in use will need to be present. This will require that multiple antennas be available to the radio (i.e two different antennas plugged into the radio on two different antenna ports).

The SDR allows SWECS to transmit node to node or node to hand-held at a frequency determined to work best underground (or to work with existing systems such as leaky feeder radios), and then switch to a low frequency in order to transmit data through the earth to a matching node on the surface. The node on the surface will need to be above the underground node to within a certain radius, but that distance has yet to be tested for. The system can also be configured such that in an emergency if multiple nodes are disabled, the node to node transmission can be via a lower, earth penetrating frequency that can hop over the disabled nodes, even through a major roof fall, in order to reestablish the network link.

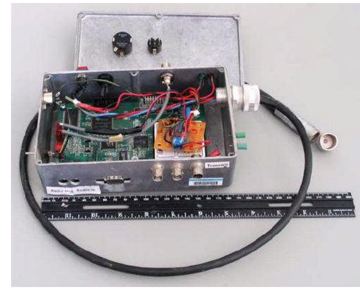
SWECS will be fully portable so that a node network need not be in place. In this case, the radios can be cached or carried by individuals for through the earth communication.

Specifications:

- Stage: Working Prototype
- Devices: Two SWECS units (radio, PDA, and antenna)
- Function: Two-way, real time digital voice and data either node to node or TTE
- Range: Tested to >800 ft TTE
- Frequency: Multiple depending on desired use. Very low frequency (<10kHz) for TTE or extended range node to node and higher frequencies for peer to peer and hand-held to node communication.

- Antenna: Depends on frequency being used, TTE uses wire wound ferrite rod
- Features:
    - PDA interface allows graphic display of mine maps with position information included.
    - Fully portable
    - Radiolocation of underground units from the surface is possible.
    - Tracking feature based on signal strength can be added.

<u>Vital Alert's Canary 2 System</u>



The Canary 2 system is a two-way, real-time prototype communication system that uses very low frequency (<10kHz) signals to transmit through the earth. The system allows an individual to talk between the underground and the surface through the earth without a hard-wired connection outside the mine. The system uses one surface unit to communicate to several underground units. The miners can then communicate with the surface using handheld radios.

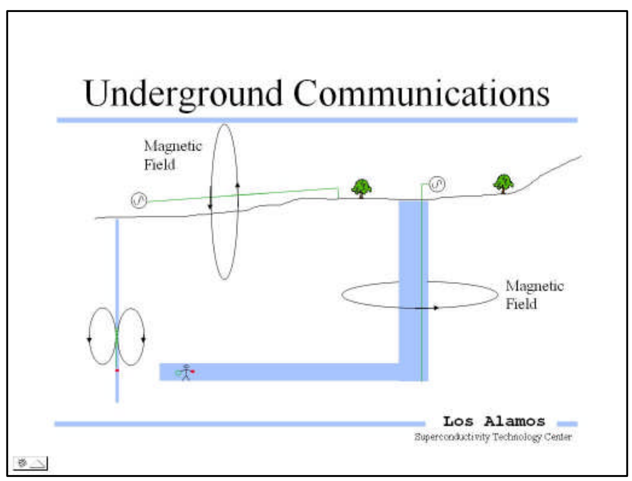
Specifications:

- Stage: Working Prototype
- Devices: One surface unit and several underground units with handheld radios
- Function: Two-way, real-time digital voice and data through-the-earth
- Range: Tested to 400 feet through the earth; maximum range TBD
- Antenna: wire-wound high μ rod (ferrite) with a semiconductor amplifier

Prototype Issues:

- Not yet Permissible or Intrinsically safe
- No built-in tracking
- Interference with devices operating off the same frequency as handheld radios
- Unit has problems communicating directly under dc electric railway
- Observed noise in some preliminary tests
- Further testing is required to determine capabilities in underground mines

Development:




This product was developed out the Los Alamos National Laboratory and licensed to Vital Alert. Research was done on various ideas for an underground radio including the use of high temperature superconductors.

This technology was also developed to use in subway systems, skyscrapers, airports, refineries, power plants, marine and port security, tunnels, bridges and commercial and industrial buildings. This technology can be adaptable to many different environments. In order to provide the best performance to all applications, the Canary 2 project looked at various signal types and performance and chose components based on those studies.  It is also based off the original Canary mine messenger technology which has already been commercialized.

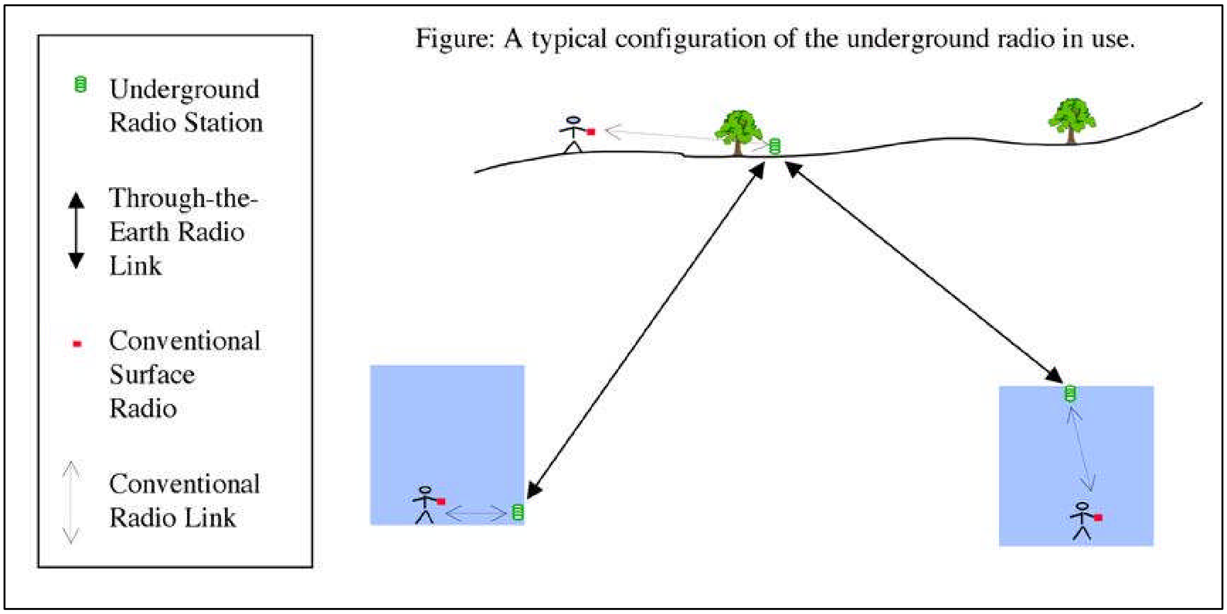



Figure: A typical configuration of the underground radio in use.

## Innovative Wireless Technologies' AXON Tranceivers

The AXON module from Innovative Wireless is a transceiver module that is designed to work with the IEEE 802.15.4 specification. It is deployed as an ad-hoc mesh network. Fixed nodes will be stationed throughout the mine while individual personnel will carry hand-held units. It is capable of both wireless data transmission and real-time tracking; voice and text capabilities are planned. The nodes are designed to run both Zigbee™ and Synaptrix™, which is an Innovative Wireless proprietary mesh-networking software stack. There are 2.4GHz, 915 MHz, 433MHz and UltraWide Band modules available. A Graphical User Interface (GUI) is used for a visual tracking display and for remote access to communications between nodes.

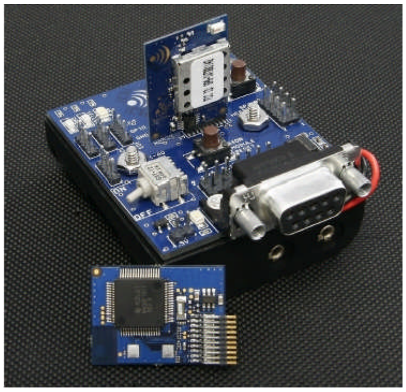


Figure 1. A single AXON node.

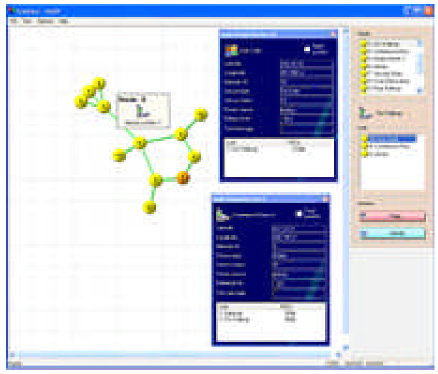


Figure 2. Screenshot of GUI showing node positions

Specifications:

- Stage: Working Prototype/Development Kit
- Devices: AXON modules as stationary nodes and handhelds.
- Function: Tracking and Sensor Data transmission; Voice and/or Text to be added.
- Range between nodes: TBD
- Frequency: 2.4GHz, 915MHz, 433MHz or UltraWide Band
- Antenna: Onboard
- Features:
    - Tracking based on signal strength (2.4GHz, 915 MHz, and 433MHz models) or time of flight measurements (UWB model).
    - Small size, low cost nodes.
    - Fully portable, low power (battery) operation.
    - Ad-hoc mesh network allows redundant infrastructure to be built.

## Rajant BreadCrumb System

The Rajant BreadCrumb System consists of nodes that utilize the IEEE 802.11b WiFi networking standard at 2.4 GHz. The nodes are portable and can operate off of line power with battery backup. Several nodes combine to create an ad-hoc mesh network. The network can be deployed as a stand alone wireless network within a mine or may be connected to other networks on the surface with communication links outside the mine such as satellite modem, DSL, cable modem, etc. The function of this system is comparable to a Local Area Network in an office setting, with the advantage of completely wireless communication.

Several different models are available in the BreadCrumb line of products; any two within range of each other can establish a network. The basic unit is the SE model, which provides two radios and an Ethernet port. The XL is the long-range model, capable of 11Mbps communications at distances of 6 miles line of sight on the surface, and lower-speed communications at greater distances. The XLE includes an MPEG video encoder; adding a composite video source will provide a video stream to the network. Two smaller units (the WE and ME) provide at least one radio each and an Ethernet port. The WE is portable. Voice communications are provided by Voice Over IP (VOIP) wireless phones or PDAs.

Specifications:

- Stage: Available – system currently marketed to several industries
- Devices: Any two models (WE, ME, SE, XL, and XLE) in range of each other establish a network
- Function: Two-way, real-time voice, data, and video
- Range: Variable among the units, underground range TBD
- Options:
  - Can integrate the system into mine infrastructure for monitoring belts (production), air quality and quantity, communications, etc.
  - Limited tracking (or association mapping) is available

System Issues:

- Not yet permissible or intrinsically safe
- Tracking capabilities are limited to nearest node, checkpoint type tracking. However, enhancing this capability through signal strength measurements is being investigated.
- Underground range and interference issues will be established after in-mine testing.

Current deployments:

The BreadCrumb system is currently used by the military and police, SWAT, fire fighters, and other first responder agencies in the US. It has also been used to establish communications in areas that have experienced natural disasters. This market establishes the product’s durability, portability, and reliability.

## Time Domain/Concurrent Technologies Corporation Ultra-Wide Band Radio Communications and Tracking System

The appeal of Ultra-Wide Band (UWB) radio is that it is a different technology as compared to other systems being evaluated. Other systems implement communications by using one frequency or another (narrowband), going up and down the frequency spectrum depending on the desired result, i.e., from low frequency for through the earth to high frequency for large data rates. Narrowband signals are continuous sine waves spanning a few MHz while UWB signals are short pulses that contain many GHz of the radio spectrum. The result is high bandwidth but low energy on any one frequency. The energy is spread enough that UWB resides below the noise floor so interference from and to other RF systems is negligible. UWB systems are inherently low power which will help in designing components to meet permissibility requirements.

The pulsed UWB signal also performs well in a high multipath environment such as an underground mine. Continuous narrowband signals bounce around and can destructively interfere with one another, limiting the range at which a signal can be received. In a tracking application, multipath interference on a narrowband system will result in limited accuracy. With UWB, the short pulses can be distinguished from one another and multipath interference is much less of a problem. Range resolution on the order of inches is possible.

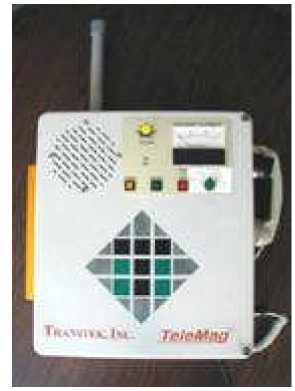
Time Domain builds radios that use UWB signals as compared to conventional narrowband radio signals. The Time Domain system spans frequencies of 3.1 to 5.5 GHz. This system can be used to build a wireless network similar to an 802.11-based LAN system. A network of stationary nodes would need to be in place in the mine to create a wireless network. Each miner would carry a radio that would act as a communication device as well as a tag for tracking purposes. The radios can communicate peer to peer as well as hand-held to node. Using range information from nodes to hand-helds and known node locations, precise locations of hand-held devices can be found.

UWB signals can penetrate through several feet of some material such as concrete blocks and debris so communication can be established through stoppings and some roof falls.

In emergency situations, the data rate can be automatically decreased to allow a network link to be established at further distances between nodes. This feature is useful to span nodes that are out of commission.

Time Domain UltraWide Band radio.

## Transtek's Telemag System



The Telemag system is a two-way, real-time prototype communication system that uses very low frequency (<10kHz) signals to transmit through the earth. The system allows individuals to talk between the underground and the surface without a hard-wired connection outside the mine. The system has identical surface and underground units that use a loop of wire to induce magnetic waves and penetrate deep into the earth.

Manufacturer's Specifications:

- Stage: Working Prototype
- Devices: Two identical Telelmag units and antennas on the surface and underground
- Function: Two-way, real-time digital voice and data through-the-earth
- Range: Tested to 280ft through-the-earth; Maximum depth TBD
- Antenna: 180-foot loop antenna cable laid out on surface/mine level floor
- Options:
    1. Mobile Handheld Radios: 600-foot radius range from underground unit
    2. Fixed position telephone handsets
    3. Panel speakers and microphones mounted in control modules
    4. Custom interface to telephone, computer network, security system or other required device system
    5. Interface to ComCell in-mine system
    6. Interface to ResQCom rescue-team system

Prototype Issues:

- Not yet permissible or intrinsically safe
- Portable, but not man self-portable
- No built-in tracking
- Requires underground and surface antennas lined up within 300 feet horizontally
- Interference with devices operating off the same frequency as handheld radios

Preliminary Testing:

Preliminary Testing was conducted at NIOSH's Lake Lynn facility in West Virginia on February 3rd, 2006. The system resided at the facility at the time and was available for testing. The Lake Lynn facility is an experimental limestone mine with

approximately 280 feet of overburden at the point of testing.

A series of broadcasts were sent from both surface to underground and underground to surface using both the Telelmag units and the handheld radios.  Both devices worked in real-time and allowed for good-quality, two-way voice communication through the earth.  The underground handheld radio functioned properly at approximately 100 feet from the underground Telemag unit.

<u>**Geosteering's Minertracker**</u>

The Geosteering Minertracker is a tracking system that uses the existing field generators and personal alarm devices (PAD) that were developed for use with Geosteering's TramGuard proximity protection system which has been MSHA approved. Each miner's PAD communicates via UHF to field generators located at various points around the mine. The field generator will then transmit the ID numbers of each PAD that it is in contact with through the earth using very low frequency (<10kHz) signals to surface mounted receivers. Each PAD and field generator will have a unique ID; by knowing which field generator the PAD is in contact with as well as each field generator position, location of the PAD can be determined. Using buttons corresponding to certain messages, information can be sent from the PAD, through the field generator, to the surface. The system will use line power and have a back up battery.

Specifications:

- Stage: Working Prototype
- Devices: PAD tag unit, underground magnetic field generator, surface receiver
- Function: Tracking to nearest field generator
- Range: Tested to 400 feet through the earth; maximum range TBD
- Antenna: loop conductor


Figure 1: PAD unit.